Geodesic Wing Structural Optimization and Dynamic Analysis

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This report summarizes the construction of finite element models, validation of honeycomb finite element models, and preparation of a task road map for the future work. Finite element models were constructed based on two planform shapes. One is the planform of the intermediate complexity wing (ICW) model and the other is a rectangular (including square) planform. Two types of finite element models were generated in each planform: one has a honeycomb core with face sheets on top and bottom which are connected by rod elements while the other is a full-depth model, consisting of plates only. The finite element models of the honeycomb sandwich structures were compared to results from Hexcel Company verification models and to an actual test result. The road map for the task includes all the procedures necessary to perform the task efficiently, starting with model construction and validation of analytical predictions.

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FOREWORD

This report was prepared by the Aerospace Structures Information and Analysis Center (ASIAC), which is operated by CSA Engineering, Inc. under contract number F33615-94-C-3200 for the Flight Dynamics Directorate, Wright-Patterson Air Force Base, Ohio. The report presents the work performed under ASIAC Task No. T-26. The work was sponsored by the Design Development Branch, Structures Division, Flight Dynamics Directorate, WPAFB, Ohio. The technical monitor for the task was Dr. V. B. Venkayya of the Design Development Branch. The study was performed by Dr. Young In Moon, CSA Engineering Inc.

This technical report covers work accomplished from February 1996 through June 1996.

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1.0 Scope of the Work

This report summarizes the construction of finite element models, validation of honey-comb finite element models, and preparation of a task road map for the future work.

Finite element models were constructed based on two planform shapes. One is the plan-form of the intermediate complexity wing (ICW) model and the other is a rectangular (including square) planform. Two types of finite element models were generated in each planform: one has a honeycomb core with face sheets on top and bottom which are con-nected by rod elements while the other is a full-depth model, consisting of plates only.

The finite element models of the honeycomb sandwich structures were compared to results from Hexcel Company verification models and to an actual test result.

The road map for the task includes all the procedures necessary to perform the task effi-ciently, starting with model construction and validation of analytical predictions.

2.0 Construction of Finite Element Models

Three types of models were constructed: ICW type, honeycomb sandwich structures model, and full-depth models.

2.1 ICW type models

The ICW finite element model is composed of spars and ribs with surface sheets which are either flat or curved and is shown in Figure 1(a). The face sheets were modeled by CQUAD4 elements, while CROD and CSHEAR elements were used to represent spars and ribs.

2.2 Honeycomb Sandwich Models

This type of models has the standard hexagonal honeycomb as a core which is attached between two faces of sandwich panels. Honeycomb sandwich finite element models use CQUAD4 elements for face panels and core cells are represented by CSHEAR and CROD elements. A typical honeycomb sandwich model is shown in Figure 1(b).

2.3 Full-depth Models

A full-depth finite element model is composed of only one element type:CQUAD4. How-ever, the mechanical properties of the CQUAD4 element need to be verified from testing a specimen based on the size and density of the honeycomb core cells. Figure 1(c) shows a full-depth finite element model.
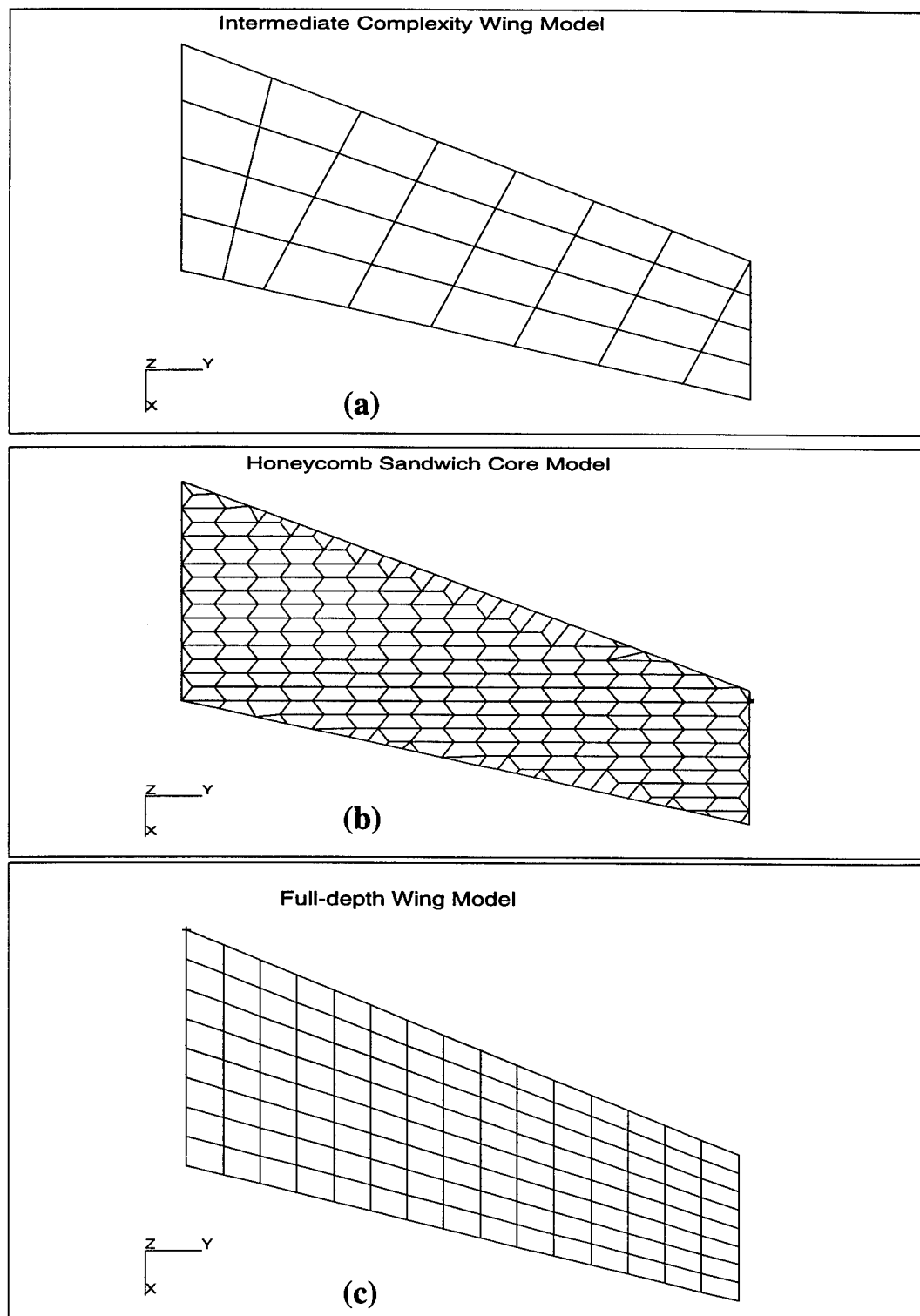
FIGURE 1. Finite Element Wing Models on ICW platform

2.4 Comparison of Rectangular Models

Figure 2 shows the planform of the three rectangular finite element models. The model is cantilevered at the left end and a total load of 200 lbs was applied at the right tip. The spar-rib model consists of top and bottom skin, spars and ribs. The skin has 0.25 inch thickness, and spars and ribs were modeled with 0.125 inch shear elements and rods have an area of 0.02 in**2. This spar-rib model weighs 292.07 lbs. The honeycomb sandwich model was made of 0.25 inch face sheets, and 0.01 inch thick shear elements representing honeycomb cell wall. The weight of this honeycomb model was 235.46 lbs. The full-depth model was composed of 0.50 inch thick plate elements with a PSHELL card which defines the membrane, bending and transverse shear properties. This model weighs 230.58 lbs.

Deflections were obtained along the middle section from the fixed end to the tip and are plotted in Figure 3 for the three models. The honeycomb model shows the maximum deflection of 0.234 inch at the tip while the spar-rib (ICW) and full-depth models show the tip deflection 0.204 inch and 0.1925 inch, respectively. As the ICW model weighs much more than the two other models, the weight was lowered to 245.97 lbs by reducing the thickness of the face sheets from 0.25 inch to 0.20 inch, and the tip deflection was found to be 0.2554 inch. This implies that the weight of ICW model should be 265 lbs to yield the same deflection (0.234 inch) as the honeycomb structure. The benefit of using honeycomb sandwich structures can be observed even in this simple example.
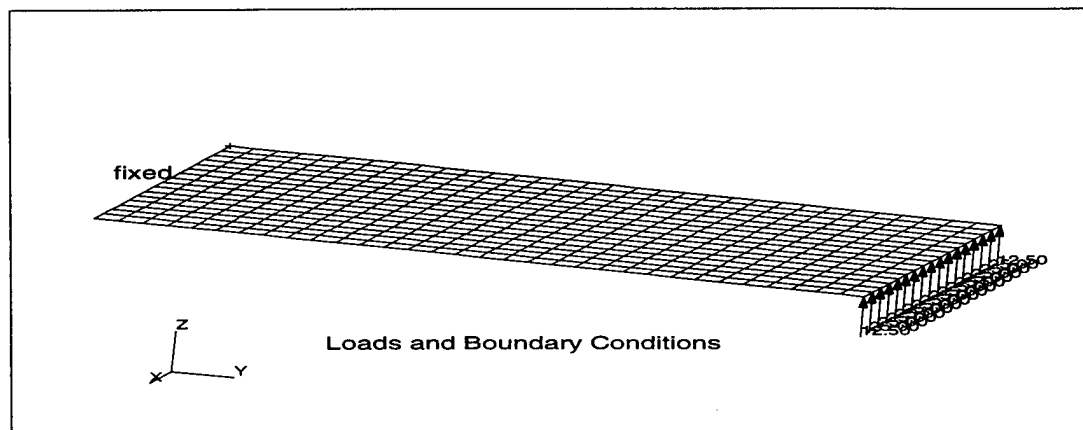

FIGURE 2. Rectangular Finite Element Model

3.0 Validation of Honeycomb Finite Element Models

To validate honeycomb sandwich finite element models, a number of models were constructed based on size and thickness of honeycomb cells, depth of the model, and shape and size of the planform. When compared to results from the Hexcel Company, maximum deflections under the same loading and boundary conditions between two types of models were not always close. It was found later that the Hexcel Company data were based on equations from MIL-HDBK-23A which was used to compute deflections. However, they did provide a series of actual test data (load-deflection curves from the three point load test) which were very close to analytical predictions obtained from running honeycomb sandwich finite element models as shown in Figure 4. The test results in Figure 4 shows a non-linear behavior of the honeycomb test specimen at the lower level of loads while both finite element models exhibit a linear behavior from the beginning. The nonlinearity in the test specimen is believed to come from the fact that the effect of loading at the early stage does not reach the whole structure but covers only the local area of loading. The honeycomb model predicts, in general, deflections very close to the test results.

4.0 Road Map for the Task

The following is a general road map which denotes the approach being used to analyze the honeycomb structures.

4.1 Validation of Modeling Approach

Technical data and literature for analytical solution of classical boundary conditions were gathered. Then a technique to model honeycomb sandwich structures for a classical boundary conditions was developed. The first model was a rectangular honeycomb sandwich plate composed of aluminum facing and honeycomb core. Analytical results predicted by the finite element models are compared with calculations from a text book or commercial companies such as Hexcel Corporation Company.

4.2 Failure Modes in Sandwich Structures *

Listed below are eight failure modes with brief descriptions.

1. General Buckling: caused by insufficient panel thickness or core shear rigidity

2. Shear Buckling: caused by low core shear modulus, or low adhesive strength.

3. Face Wrinkling: this is face buckling as a plate on an elastic foundation. It comes either adhesive bond failure or core compression failure.

4. Dimpling is an intracell buckling and occurs with very thin facing and large core cells.

5. Facing Failure: caused by insufficient panel thickness, facing thickness or facing strength.

* Design Handbook for Honeycomb Sandwich Structures,TSB 123, March 1970,Hexcel Corporation

6. Transverse Crushing of Core: caused by insufficient core shear strength or panel thickness.

7. Flexural Crushing Core: caused by insufficient core flatwise strength or excessive beam deflection.

8. Local Crushing of Core: caused by low core compressive strength.

4.3 Customization

The honeycomb cell size, depth of the structure and thickness of face plates will be modified to the requirements of the ICW model.

4.4 Optimization

Optimize the rectangular honeycomb and ICW finite element models for weight.

4.5 Use of Composites

Use composite facing and composite shear panels for honeycomb cell for both rectangular and ICW models.

4.6 Trade Study for Improvement

Change the ICW model for airfoil shape, and analyze and optimize the model.

4.7 Simulation of Hydrodynamic Ram

Use the generated finite element models to simulate the hydrodynamic ram effect using MSC/DYTRAN program.

4.8 Non-linear Analysis

Consider non-linear effects of hydrodynamic ram.

4.9 Dynamic Effects

Consider air loads and perform aeroelastic analysis, and optimize for weight.

5.0 Conclusion

Under this task, a number of finite element models were constructed, and a honeycomb sandwich structure model was validated against the test data and a road map for the present and future work was prepared.
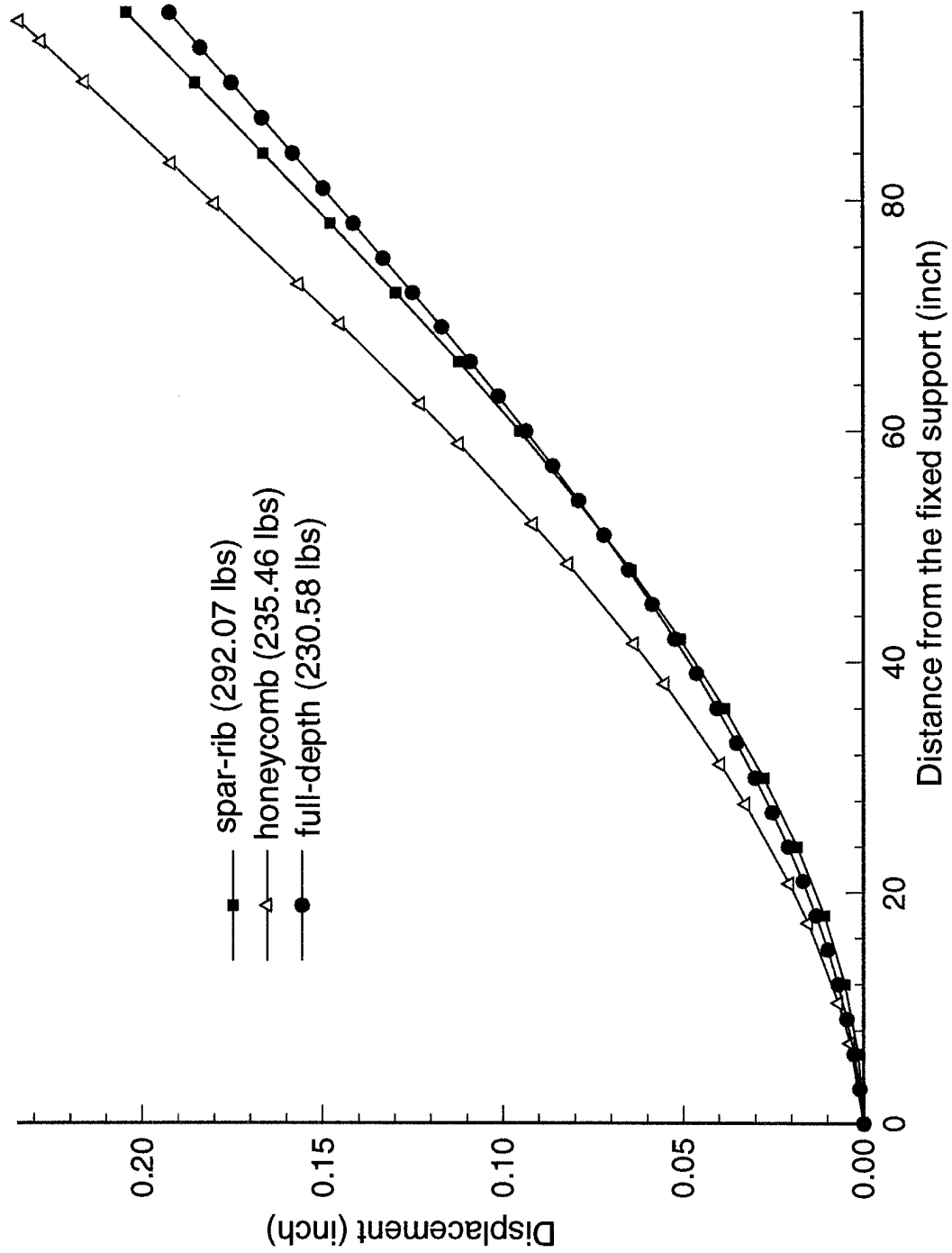
FIGURE 3. Comparison of Three Models

spar-rib (292.07 lbs)
honeycomb (235.46 lbs)
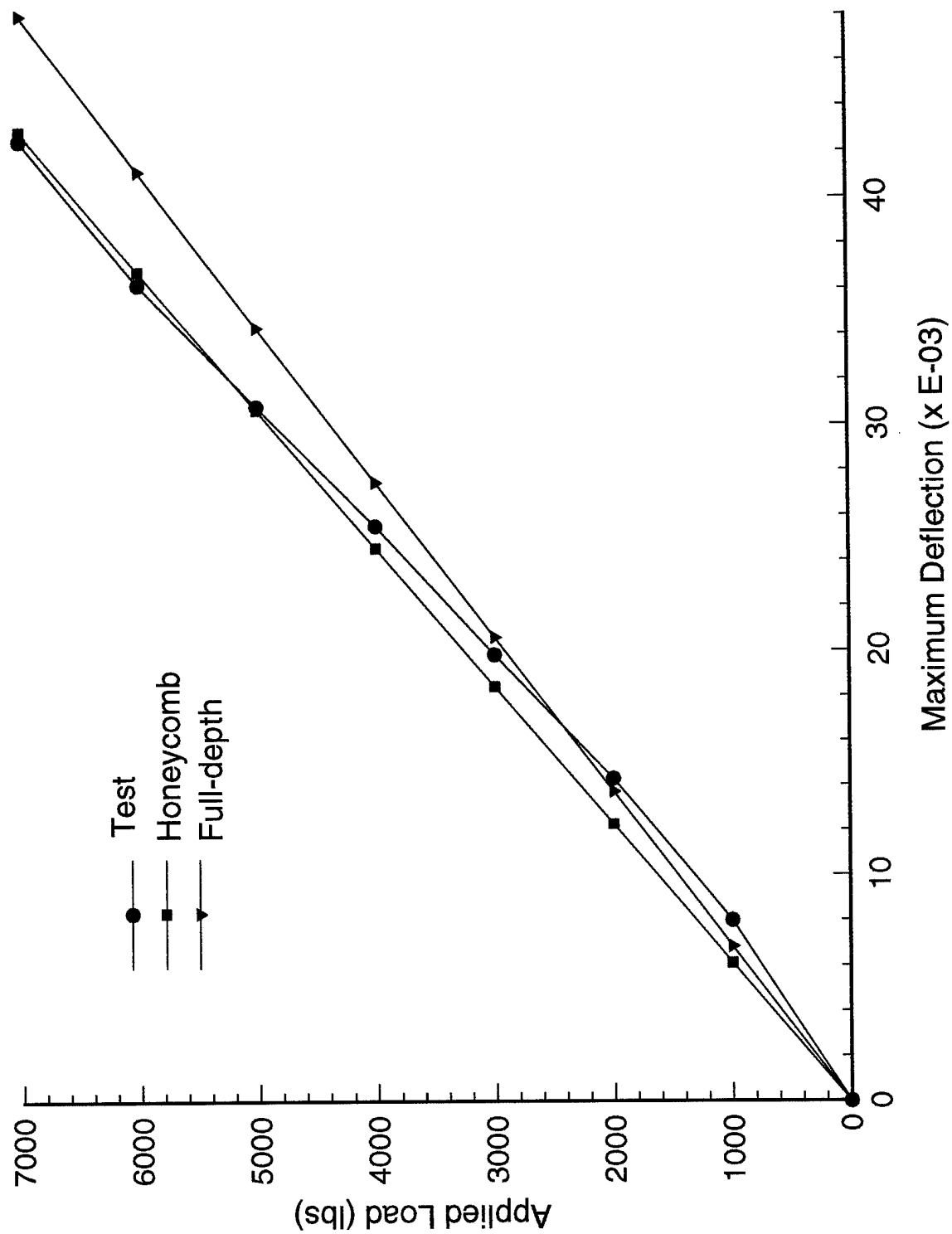full-depth (230.58 lbs)

Distance from the fixed support (inch)

Displacement (inch)

6

FIGURE 4. Validation of Finite Element Models